# THE PREDICTION OF SURGES IN THE SOUTHERN BASIN OF LAKE MICHIGAN

## Part II.[1] A Case Study of the Surge of August 3, 1960

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### ABSTRACT

Surface weather observations and barograph traces from the region surrounding the Great Lakes were analyzed for the hours 0300 to 1300 CST, August 3, 1960. Synoptic and time-section analyses of the surface weather show the squall line which moved across the southern part of Lake Michigan between 0900 and 1000 CST. An isochrone analysis of the pressure jump also is presented.

Records from several water-level recording gages in the Southern Basin of Lake Michigan are transcribed, and show clearly the surge which was produced by passage of the squall line over the Lake.

From transit times at eight stations in the region surrounding the Southern Basin, the average speed and direction of motion of the squall line have been determined. Lake-level data for the surge caused by the squall line of August 3, 1960, are compared with the lake levels computed by Platzman for a squall line moving with similar speed and direction.

## 1. INTRODUCTION

On the morning of August 3, 1960, an intense squall line moved rapidly across the southern part of Lake Michigan. The disturbance of lake level formed by the combined action of the intense pressure gradient and strong winds was reflected from the southeastern shore, and caused water levels along the Chicago lakefront to rise and fall with an amplitude of 2 to 4 ft.

This was the first prominent occurrence of the surge phenomenon in Lake Michigan since 1954, when two strong surges occurred (June 26 and July 6). The sudden and unexpected rise in lake level on June 26, 1954, caused several drownings at the entrance to Montrose Harbor (Chicago), and the interest aroused in the formation of such waves resulted in several papers on the subject (see references [1, 3, 5, 6]). Platzman [6] used a dynamical model and made numerical calculations of the fluctuations in water level produced by the movement of a squall line across Lake Michigan. From an analysis of a series of calculations using different squall-line speeds and directions he has shown that the peak stage in the vicinity of Montrose Harbor is highest for a squall line moving southeastward at 54 kt. [7].

The results of the numerical calculation were used in the U.S. Weather Bureau Chicago Forecast Center on August 3, 1960, when estimates of squall-line intensity, speed, and direction indicated that formation of a surge probably would accompany passage of the squall line over the Lake. A provisional forecast was issued to the public at 1045 CDT, warning of the possibility of a rise in lake level around noon. The Chicago Park District sent officers to the beaches to warn bathers of the imminent surge. The outcome of this timely warning was that the Chicago beaches were clear when the water rose at noon, and no drownings occurred. (One man was drowned when his boat capsized in the waves whipped up at the time of the squall-line passage.) For further details of this surge forecast, see the paper by Hughes [4].

The purpose of this report is to present data related to the storm and surge of August 3, 1960, and to compare the details of the rise and fall of lake level with Platzman's numerical computations.

## 2. DATA

The data used in the surface weather map analysis and the isochrone analysis of the pressure jump presented here came from two main sources: WBAN 10 [4] and microbarograms. The sequence of maps in figure 1 shows the surface weather analysis for each hour from 0300 to 1200 CST, August 3, 1960. An isochrone analysis of the pressure jump is shown in figure 2.

Careful analysis of the data revealed the existence of two pressure-jump lines of interest. The first (designated I) was located in northern Minnesota at 0000 CST and moved southeastward into Wisconsin, maintaining a speed of about 42 kt. until 0700 CST. Then its speed increased to about 60 kt. and at the same time it weakened

[1] Part I (by G. W. Platzman) and Part III (by L. A. Hughes) appear elsewhere in this issue of the *Review*.

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[4] WBAN 10 is the form used by the U.S. Weather Bureau for recording surface weather observations.

until by 0900 CST it had dissipated. During the last two hours of its existence all that remained to identify it were a slight wind shift and a small rise in pressure (less than a millibar).

The second pressure-jump line (II) formed in southern Wisconsin between 0600 and 0700 CST, and moved southeastward behind system I at a speed of 55 kt. As this pressure-jump line, accompanied by thunderstorms, moved across southern Wisconsin and northern Illinois, it left in its wake a path of destruction—many trees were uprooted by the high winds, barns and houses were damaged, and electric and telephone services were cut by trees falling on the wires. In Milwaukee many areas of the city reported flooded intersections and basements. As the storm passed over the Chicago loop at 0915 CST "it looked like 9 p.m." according to reports and the temperature at Grant Park dropped from 84° F. to 72° F. in 10 min. Wind gusts of 55 to 75 m.p.h. were recorded. The squall line continued moving across Lake Michigan and reached South Bend, Ind., at 1010 CST; there, 0.62 in. of rain fell in 5 min. As the storm moved eastward into Ohio it began to weaken, and by 1300 CST it had almost dissipated. During its passage over the region surrounding Lake Michigan, the magnitude of the pressure rise ranged from 0.04 to 0.15 in. (average: 0.08 in. or 2.7 mb.), and the duration of the rise ranged from 5 to 20 min. (average duration 11 min.).

In figure 3 we have barograms from 11 stations in the path of squall lines I and II, arranged in order of squall-line transit time. The barograph traces have been reversed in the manner described by Fujita, Newstein, and Tepper [2], so that the time section at each station resembles a space section through the stations. The pressure jumps are indicated by arrows and I and II identify the systems to which the jumps are related. Included on the same time scale are other weather observations: hourly temperature, cloud data (amount, type, and height), precipitation, wind speed and direction, plus remarks from the hourly or special observations. The arrangement of this information is shown in the model station time section (fig. 3a, upper left).

A complete mesoscale analysis was not attempted, but these station time sections, in conjunction with the maps of figure 1, show the movement of the pressure disturbances and their effect on the wind and weather. The record at Rockford, Ill., shows the sequence of events rather well. Here, the gradual thickening of lower and middle cloud was followed by the passage of the weak first squall line accompanied by a slight wind shift from light southwest to light west-northwest, light rain, and a small pressure rise. The arrival of the second squall line (II) was heralded by thunder, heavy rain, strong gusty northwest winds, and a sharp drop in temperature. It is this latter system which resulted in the surge on Lake Michigan.

From figure 1 we see that the first disturbance originated in the cool air and its passage through the frontal zone resulted in a disruption of any clear distinction between air masses so that the stationary front which had been lying across Wisconsin and Lower Michigan became very weak.

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The lake-level data for the surge which occurred on Lake Michigan following the passage of the second squall line were obtained from several sources. The following stage recorders are maintained in the Southern Basin of Lake Michigan: Waukegan and Wilson Avenue Crib (Chicago) by the Illinois Division of Waterways; Navy Pier and South District Filtration Plant by the City of Chicago Department of Waters and Sewers; and Calumet Harbor by the U.S. Lake Survey. The lake-level oscillations at these locations as transcribed from copies of the original recorder records are shown in figures 4 to 6. (The record from South District Filtration Plant was incomplete and is omitted here.) Wilson Avenue Crib is the only location representative of open-lake conditions, since all the other gages are situated in harbors or behind breakwaters so that short-period oscillations (for example, the 20-min. period of the Waukegan record and the 15–20-min. period of the Calumet Harbor record) sometimes obscure the longer-period oscillations of the Lake. The Navy Pier record exhibits strong damping of the lake-level oscillations, probably related to its location at the extreme shoreward end of Navy Pier.

Included with the Wilson Avenue Crib and Waukegan records are wind profiles and pressure traces associated with the passage of the squall line.

The Calumet Harbor record shows the peak surge at 1000 CST, about one hour earlier than shown at the other locations. This maximum must be the result of the first (primary) surge, before reflection from the southeastern shore of the Lake. The reflected wave is much less prominent than the primary wave at Calumet Harbor.

## 3. ESTIMATES OF SQUALL-LINE SPEED AND DIRECTION

Several estimates of squall-line speed and direction were made, using the transit times of pressure-jump line II at eight stations located near the Southern Basin of Lake Michigan; these stations, with transit times and pressure jump estimates, are listed in table 1. Each estimate of speed and direction was made by a triangulation method based upon the assumption that in the region between a specified group of three stations the pressure-jump line is a straight line moving with constant speed and direction. A scale was devised from which the speed and direction of the squall line were read, given the time required for the squall-line to move from station A to stations B and C, when the three station locations form a triangle. For example, for the first estimate shown in table 2, we used: time required for squall line to move from Madison to Milwaukee, 75 min.; time required for squall line to move from Madison to Rockford, 46 min. From the triangulation scale, these data give 49 kt., 119° for speed and direction of squall line.

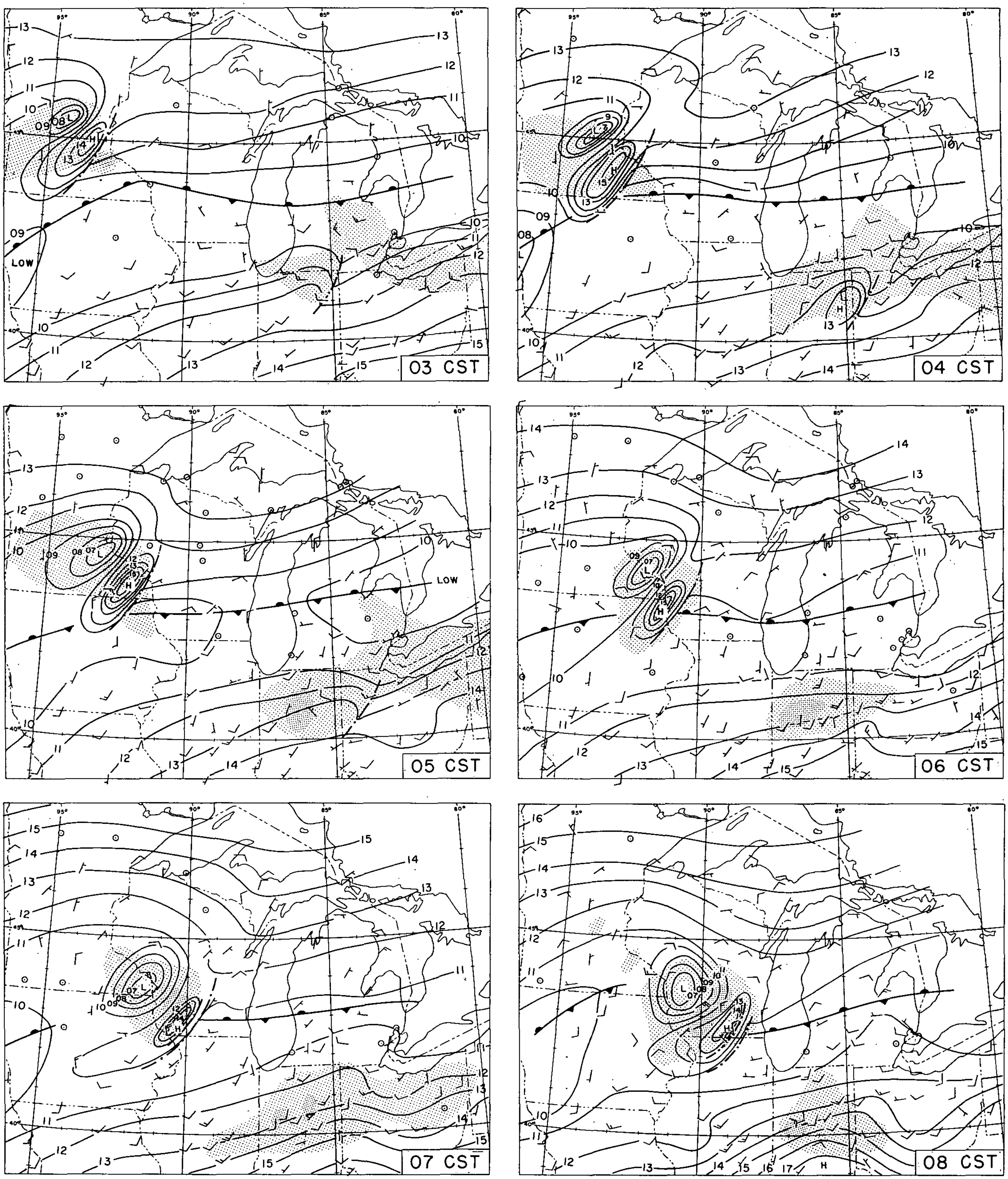


FIGURE 1a.—Surface weather analysis for each hour from 0300 to 0800 CST August 3, 1960. Isobars are labeled in millibars departure from 1000 mb.; rainfall for the hour ending at the designated time is indicated by the shaded regions (light shading for hourly rainfall exceeding 0.01 in., heavy shading for hourly rainfall exceeding 0.50 in.).

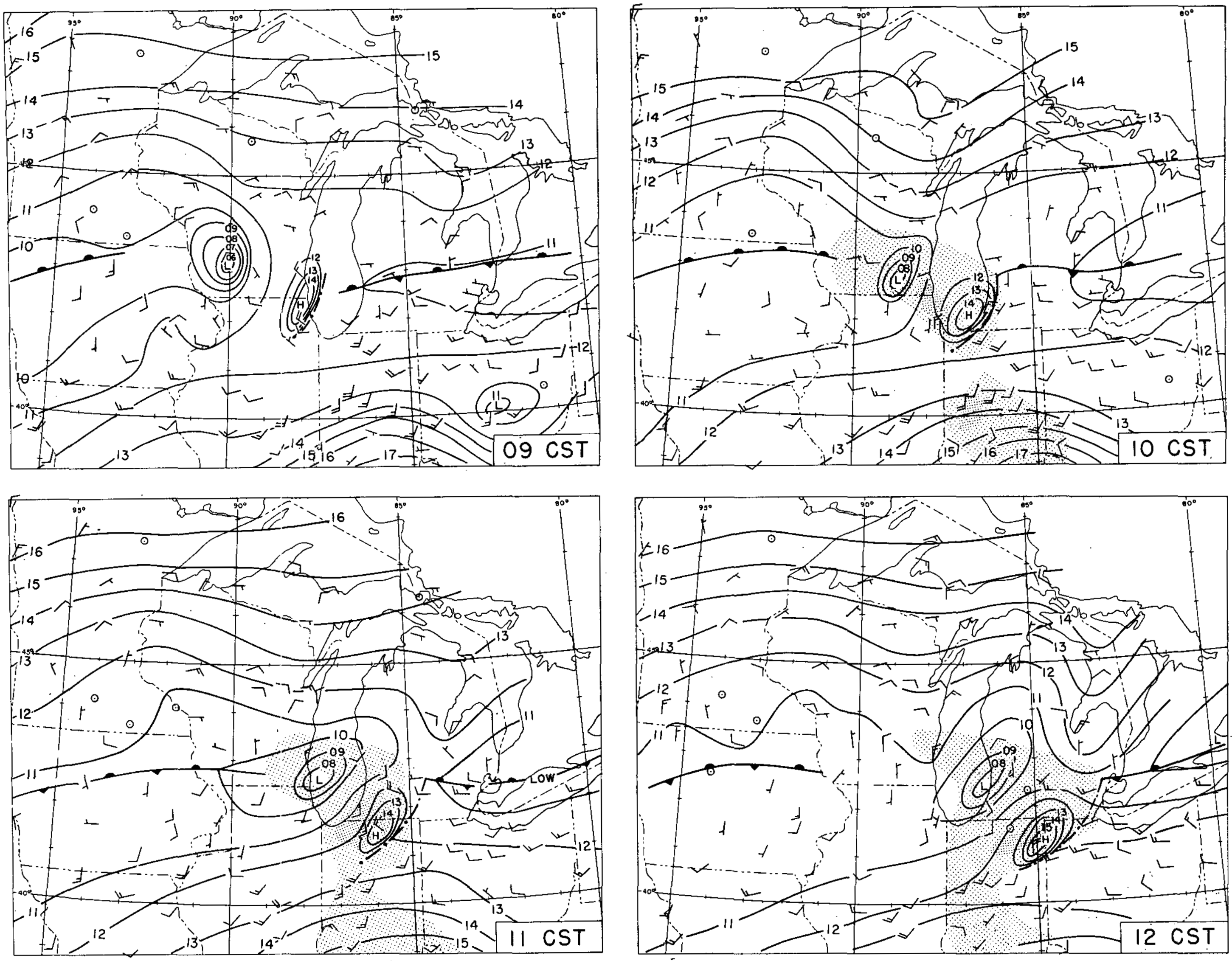


FIGURE 1b.—Surface analysis for each hour from 0900 to 1200 CST August 3, 1960.

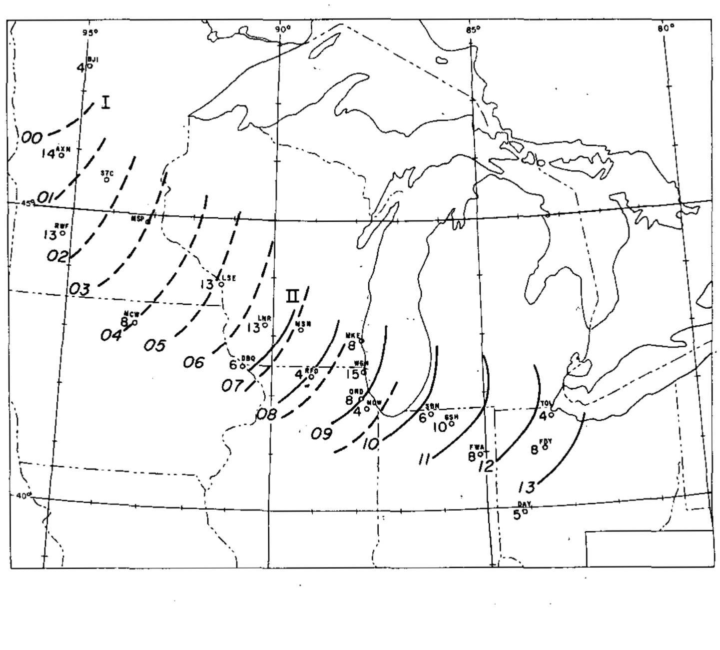

FIGURE 2.—Isochrone analysis of the pressure jumps. The systems are designated I (beginning at 0000 CST) and II (formed at 0700 CST). Pressure jumps are shown in hundredths inches at individual stations.

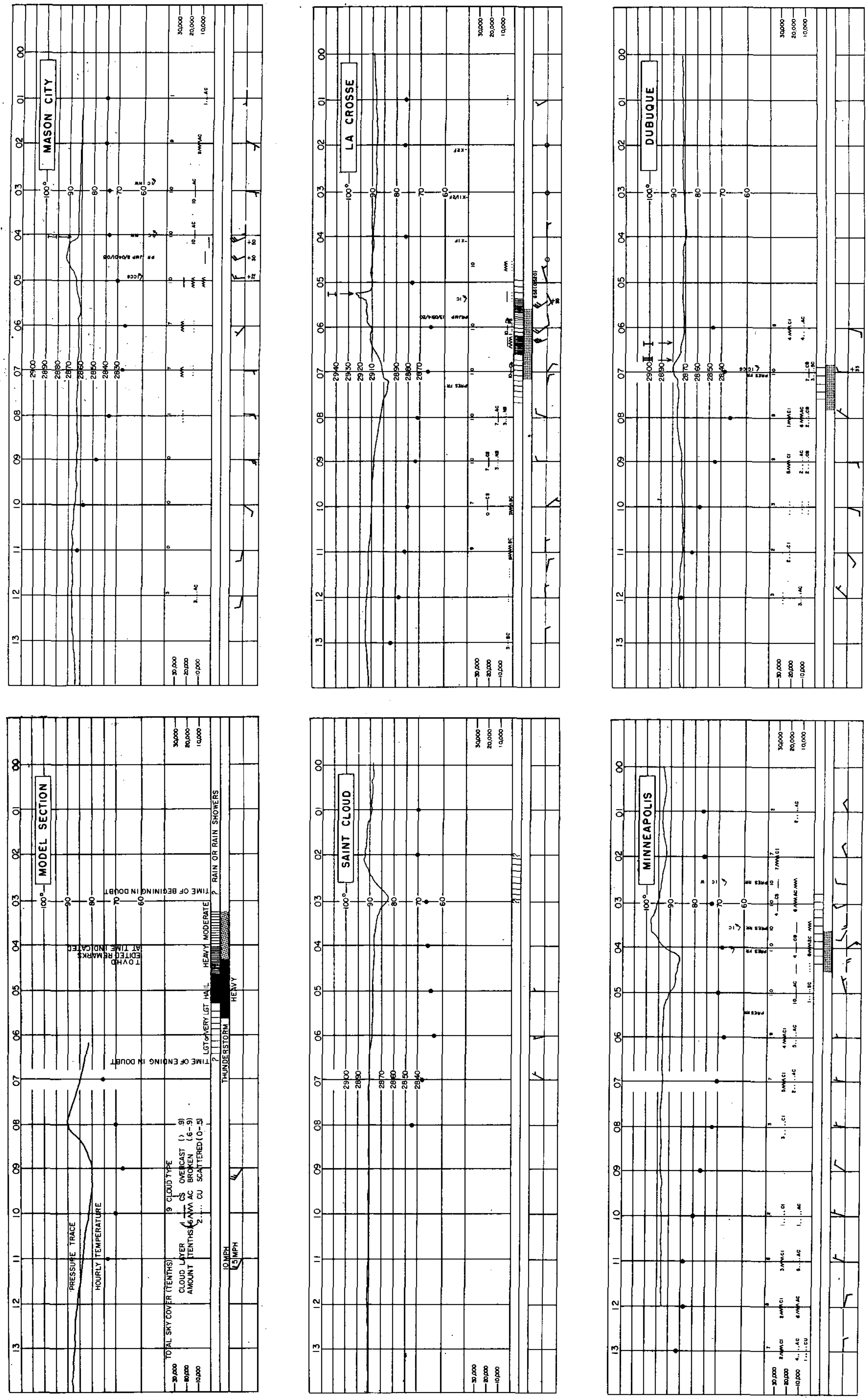


FIGURE 3a.—Station time sections for St. Cloud, Minn.; Minneapolis, Minn.; Mason City, Iowa; LaCrosse, Wis.; Dubuque, Iowa. Pressure jumps are indicated by arrows, with I and II designating the systems to which the jumps are related. The time scale runs from 0000 to 1300 CST August 3, 1960.

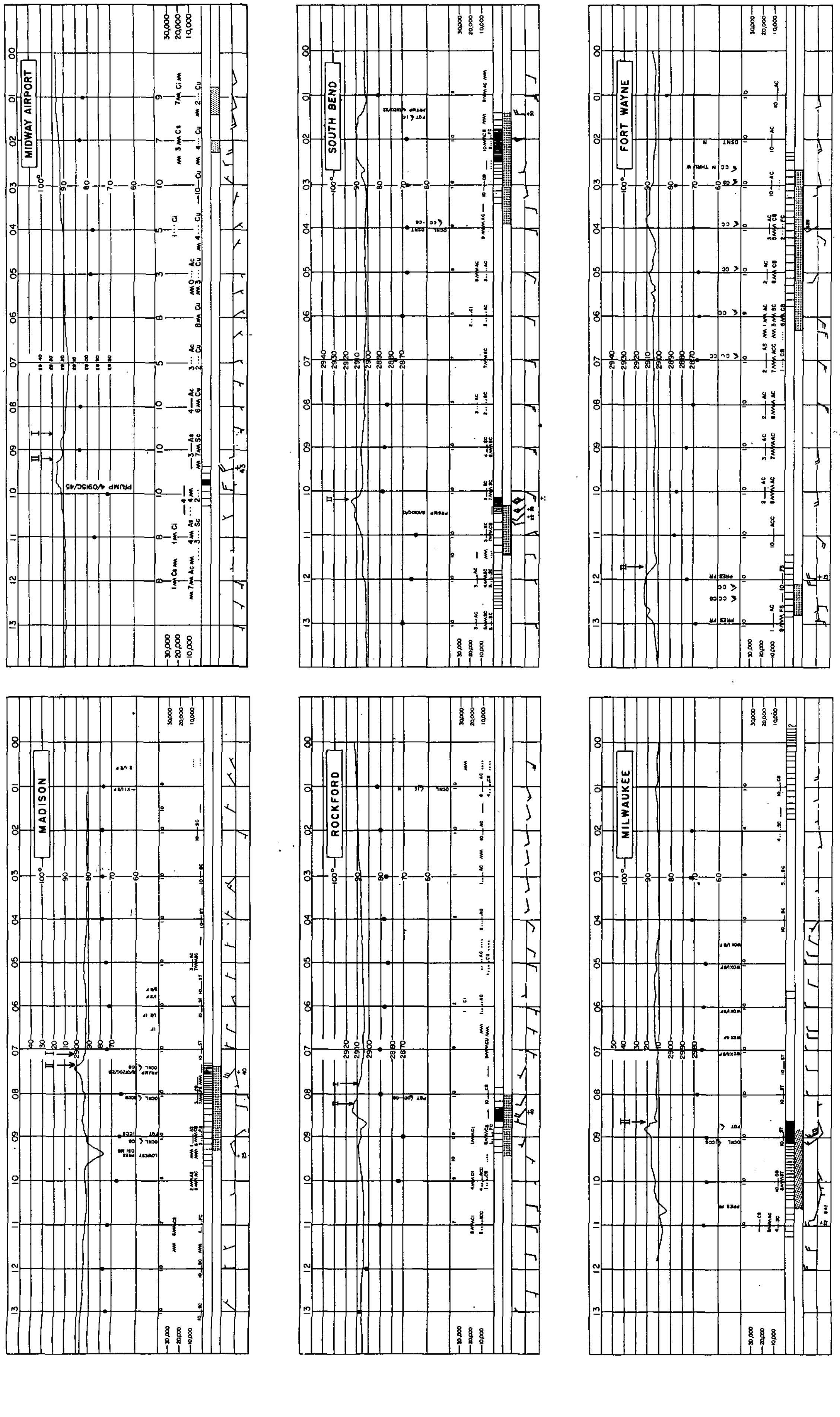


FIGURE 3b.—Station time sections for Madison, Wis.; Rockford, Ill.; Milwaukee, Wis.; Midway Airport (Chicago), Ill.; South Bend, Ind.; Fort Wayne, Ind. Pressure jumps are indicated by arrows, with I and II designating the systems to which the jumps are related. The time scale runs from 0000 to 1300 CST, August 3, 1960.

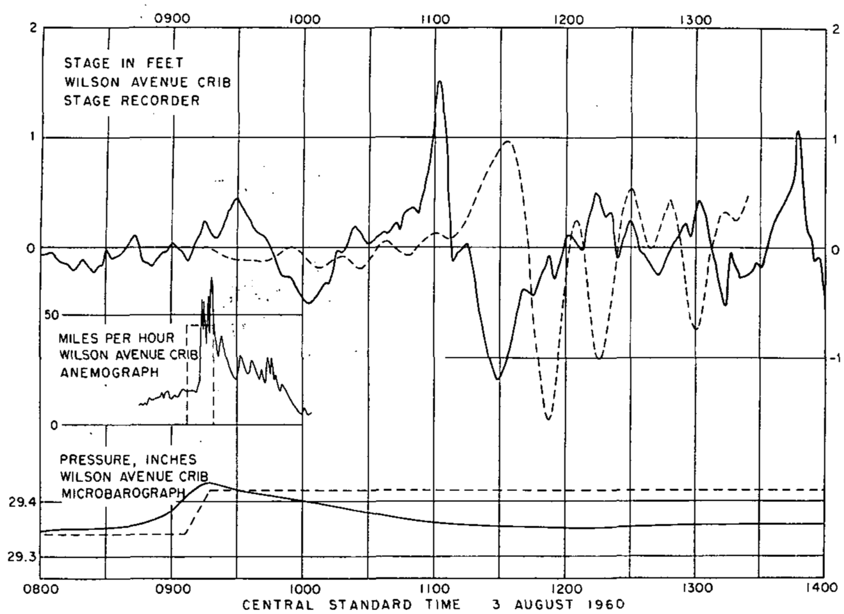


FIGURE 4.—Lake-level, wind, and atmospheric-pressure records at Wilson Avenue Crib, August 3, 1960. The broken curves of lake level, wind, and pressure are for the numerical computation for a squall line moving at 54 kt., 115° (see section 4).

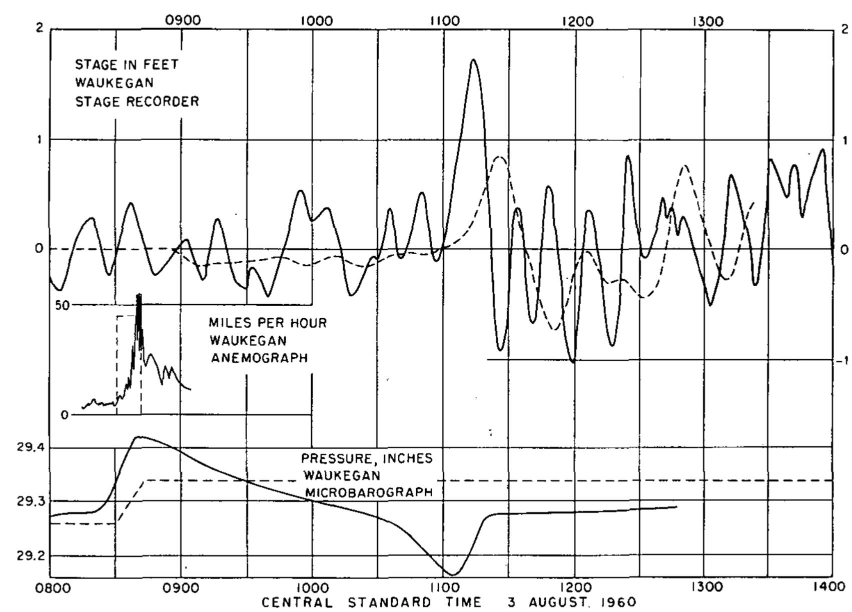


FIGURE 5.—Lake-level, wind, and atmospheric-pressure records at Waukegan, August 3, 1960. The broken curves are for the numerical computation 54 kt., 115° (see section 4).

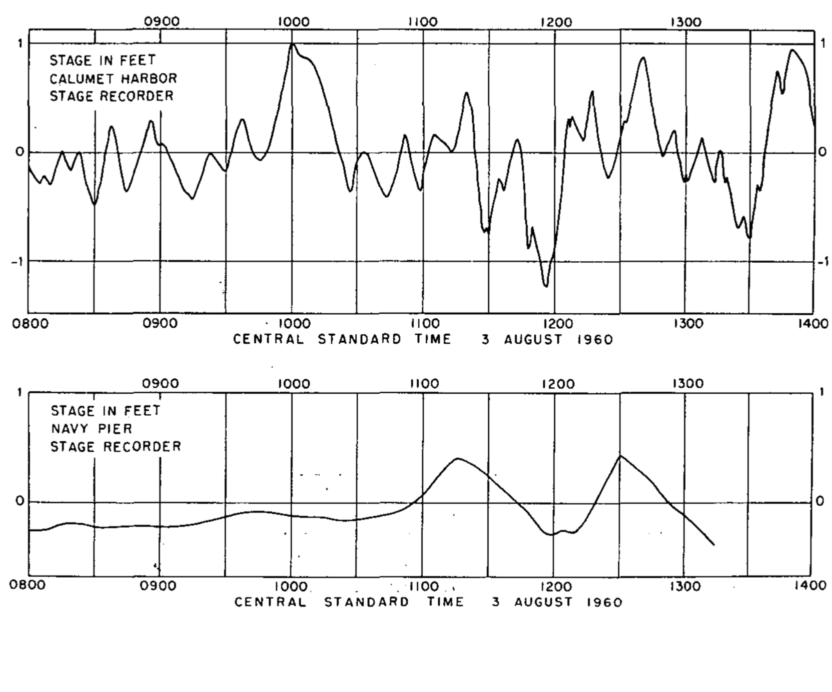


FIGURE 6.—Lake-level records at Calumet Harbor and at Navy Pier, August 3, 1960.

The locations of the eight stations are shown in figure 7. Eighteen estimates of squall-line speed and direction were made, and these are tabulated in table 2. The direction of motion is measured in degrees from north (see fig. 8).

The average speed and direction of the squall line, determined from these estimates is 53 kt., 123°. However, the fact that the pressure-jump line was strongly curved is shown in the wide range of values obtained in the estimates. Those based upon the northern triangles show a N–S orientation of the line and those based upon the southern triangles show a NE–SW orientation of the line. Accordingly, we have a bow-shaped squall line and we must regard the vector 53 kt., 123° as giving the propagation of the system as a whole.

## 4. COMPARISON WITH NUMERICAL COMPUTATIONS

The computations by Platzman [6, 7] were carried out for a squall line represented by a straight band 10 n. mi. in width, moving with constant velocity and without change of structure. The wind and pressure forces were confined to the moving band, and acted uniformly within the band in the direction of motion of the band (see fig. 8).

TABLE 1.—*Squall-line (II) transit times*

| Station | Call letters | Transit time (CST) | Pressure jump (in.) |
|---|---|---|---|
| Madison | MSN | 0720 | 0.08 |
| Rockford | RFD | 0806 | *.04 |
| Milwaukee | MKE | 0835 | *.08 |
| Waukegan | WGN | 0837 | *.15 |
| O'Hare Airport | ORD | 0900 | *.08 |
| Wilson Avenue Crib | WIL | 0914 | *.08 |
| Midway Airport | MDW | 0915 | .04 |
| South Bend | SBN | 1010 | .06 |

*These pressure jumps were estimated from the barograph traces; the others were reported at the time in the surface weather observations.

TABLE 2.—*Estimates of squall-line speed and direction*

| Stations used in triangulation* | Speed (knots) | Direction† (degrees) |
|---|---|---|
| MSN, MKE, RFD | 49 | 119 |
| ORD, MKE, RFD | 59 | 115 |
| ORD, MKE, MSN | 49 | 111 |
| ORD, MSN, RFD | 54 | 129 |
| MDW, RFD, MSN | 55 | 128 |
| MDW, MSN, MKE | 50 | 111 |
| MDW, MKE, RFD | 58 | 115 |
| WIL, RFD, MSN | 55 | 129 |
| WIL, MKE, MSN | 50 | 108 |
| WIL, MKE, RFD | 60 | 115 |
| ORD, WIL, MDW | 55 | 125 |
| ORD, WGN, SBN | 39 | 156 |
| ORD, MKE, SBN | 63 | 116 |
| SBN, MKE, WGN | 45 | 88 |
| MDW, WGN, SBN | 44 | 145 |
| MDW, MKE, SBN | 64 | 119 |
| WIL, WGN, SBN | 35 | 164 |
| WIL, MKE, SBN | 64 | 117 |
| Average | 53 | 123 |

*See table 1 for translation of call letters.
†See figure 8 for definition sketch.

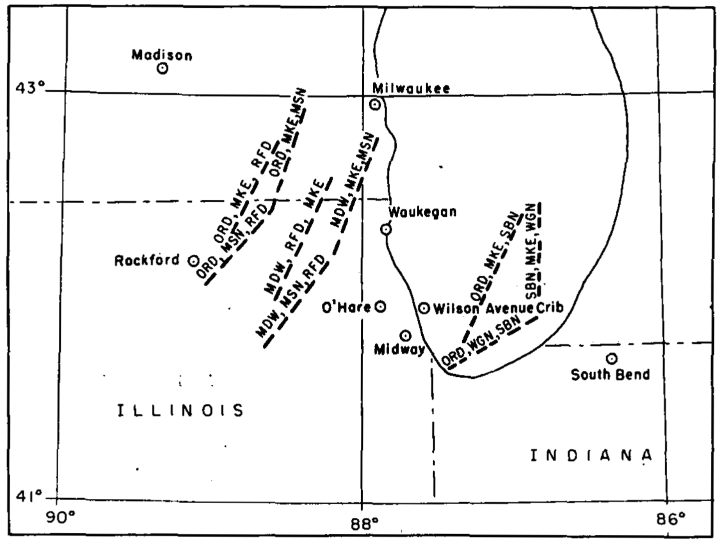


FIGURE 7.—Locations of the eight stations used to estimate squall-line speed and direction. The broken lines are estimated orientations of pressure-jump line II, each of which is determined from transit times at three stations.

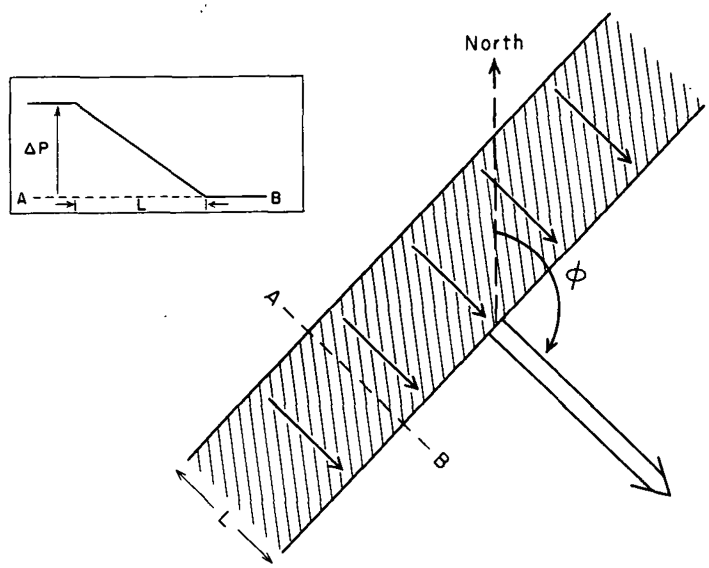


FIGURE 8.—Schematic picture of the hypothetical conditions of pressure and wind which characterize the squall line in the computations by Platzman [6, 7]. The angle $\phi$ defines the direction of motion of the squall line.

The structure of the squall line of August 3, 1960, is not so simply delineated. The pressure-jump magnitude varied from 0.04 in. at Midway Airport to 0.15 in. at Waukegan, and the duration of the pressure rise ranged from 5 min. at O'Hare and Midway to 20 min. at Waukegan. As noted above, the entire mesosystem was moving toward 123°, but the squall line was strongly curved so that its orientation varied from N–S at Milwaukee to NE–SW at Chicago. Numerical computations were made for propagation speeds of 42, 48, 54, 60, 66 kt. and directions of 95°, 115°, 135°, 155°, 175°. The broken lake-level curves in figures 4 and 5 are the stages computed for a squall-line propagation of 54 kt., 115°. Of the 25 combinations available, this one most nearly approximates the actual conditions. A pressure rise of 0.08 in. and wind of 39 kt. within the 10-n. mi. band were used in the computation. These values of wind and pressure rise were chosen to approximate those of the August 3, 1960, squall line. (The computation shown in fig. 4 is for a point which is about 0.6 n. mi. inshore from Wilson Avenue Crib; that in figure 5 is for a point about 0.4 mi. offshore from Waukegan.)

Significant features of the stage records which should be considered in a comparison between actual and computed stages are as follows: (1) time lapse between pressure-jump passage at Wilson Avenue Crib and arrival of the reflected surge there and at Waukegan; (2) time interval between first and second surges at Wilson Avenue Crib; (3) time interval between second surge and first following depression; and (4) magnitudes of second surges at Wilson Avenue Crib and Waukegan. Waukegan and Wilson Avenue Crib were chosen for this detailed comparison because they show the surge maximum most clearly and because wind and pressure records are available for both locations.

The jump arrival at Wilson Avenue Crib is taken as the reference time in order to compare times of the computed and observed events. Immediately a discrepancy is introduced, since the time interval between jump arrivals at Waukegan and Wilson Avenue Crib is 21 min. in the computation and 37 min. in the August 3, 1960, case. However, a single reference time for both Waukegan and Wilson Avenue Crib records is needed for the computations to be meaningful. The summary of time intervals between significant events in the computed and observed lake-level fluctuations is given in table 3 for Wilson Avenue Crib, and in table 4 for Waukegan. Since there was no primary (pre-reflection) surge at Waukegan in either the computed or observed stages, we give in table 4, column 3 the time difference between the arrival of the reflected surge at Waukegan and Wilson Avenue Crib rather than the interval between first and second surges (as in table 3). The mean lake level on August 3, 1960, based upon hourly readings, was 581.08 ft. (mean tide New York), and the surge amplitudes cited are based on this value of mean lake level. Examination of the information summarized in tables 3 and 4 leads to the following observations:

(1) The duration of the pressure jump used in the computation is smaller than that observed at either Waukegan or Wilson Avenue Crib. However, as mentioned earlier, the observed jump duration had a wide range, with an average of 11 min., so the 11.1 min. used in the computation is representative.

(2) The time interval between the first and second surges at Wilson Avenue Crib (table 3, column 3) given by the 115° computation compares very well with the observed, but the interval between the pressure-jump arrival and the computed second surge arrival at Wilson Avenue Crib (column 4) is 27 min. longer than the observed interval. That is, the discrepancy in column 4 is chiefly due to the fact that the *first* surge at Wilson Avenue Crib arrived earlier than was predicted. Analysis of the computed lake levels for a squall line moving toward 115° shows a surge building up first at the eastern side of the Lake and gradually spreading westward. As it develops, the surge moves ahead of the squall line in the middle and eastern parts of the Lake, but lags behind it at the western shore, so that the first surge reaches the Chicago lakefront about 40 min. after the passage of the squall line. On August 3, 1960, only 16 min. elapsed between the jump arrival and the first surge at Wilson Avenue Crib. This rapid arrival of the first surge can be explained if the surge caused by the strongly curved squall line did not lag behind the squall line at the western extremity as much as it would have if the squall line had been straight.

(3) The 115° computation predicts the interval between second surge and following depression (column 5) fairly well at Wilson Avenue Crib but the computed interval is much too long at Waukegan. This interval is predicted a little better by the 95° computation (19 min.), but the short observed interval (13 min.) may be an effect of local oscillations which appear throughout the Waukegan record of August 3, 1960.

(4) Computed amplitudes are much smaller than the amplitudes observed on August 3, 1960 (column 6). Here again the 95° computation is slightly better at Waukegan (0.96 ft.), but not at Wilson Avenue Crib (0.32 ft.). The small amplitude of the surge computed for Waukegan may be due partially to the offshore location of the point for which the computation was made. Although only 0.4 n. mi. from the shore at Waukegan, the point is 1.0 n. mi. from the virtual boundary used in the computation, so that the amplitude of the lake-level oscillations there would be less than at a location at the boundary.

(5) Comparing column 4 of both tables, we see that the reflected surge of August 3, 1960, reached Wilson Avenue Crib 108 min. after the arrival of the pressure jump, and reached Waukegan 11 min. *later*, 119 min. after pressure-jump arrival at Wilson Avenue Crib (the reference time). This lag in the arrival of the second surge at Waukegan

TABLE 3.—*Computed and observed time intervals between significant events at Wilson Avenue Crib; surge of August 3, 1960*

| | (1) (kt.) | (1) (deg.) | (2) (min.) | (3) (min.) | (4) (min.) | (5) (min.) | (6) (ft.) |
|---|---|---|---|---|---|---|---|
| Computed | 54 | 115 | 11 | 95 | 135 | 20 | 0.96 |
| Observed | 53 | 123 | 15 | 92 | 108 | 27 | 1.53 |

(1) Speed and direction of squall line.
(2) Duration of pressure jump.
(3) Interval, first to second surge at Wilson Avenue Crib.
(4) Interval, jump arrival to second surge at Wilson Avenue Crib.
(5) Interval, second surge to first following depression at Wilson Avenue Crib.
(6) Amplitude of second surge.

TABLE 4.—*Computed and observed time intervals between significant events at Waukegan; surge of August 3, 1960*

| | (1) (kt.) | (1) (deg.) | (2) (min.) | (3) (min.) | (4) (min.) | (5) (min.) | (6) (ft.) |
|---|---|---|---|---|---|---|---|
| Computed | 54 | 115 | 11 | 4 | 131 | 26 | 0.85 |
| Observed | 53 | 123 | 20 | −11 | 119 | 13 | 1.74 |

(1) Speed and direction of squall line.
(2) Duration of pressure jump.
(3) Interval, second surge at Waukegan to second surge at Wilson Avenue Crib.
(4) Interval, jump arrival at Wilson Avenue Crib to second surge at Waukegan.
(5) Interval, second surge to first following depression at Waukegan.
(6) Amplitude of second surge.

does not appear in the 115° computation, in which the surge reaches Waukegan 4 min. *before* it reaches Wilson Avenue Crib. The 95° computation does show a lag (with surge arrival at Waukegan 146 min., at Wilson Avenue Crib 137 min. after reference time: a 9-min. difference). However, in the 95° computation the whole surge arrives even later than in the 115° computation, so in that sense the 95° computation is poorer. The relative time of arrival of the second surge at the two stations is dependent on the accuracy with which the times of the two recording instruments can be compared. Although careful notation of time has been made on each chart, there still remains some uncertainty in establishing an absolute time reference for comparison between the records.

## 5. CONCLUSIONS

In summary, the internal timing of the August 3, 1960, disturbance, i.e., interval between first and second surge, or between second surge and first following depression, is predicted fairly well by the 115° computation. The 95° computation may be slightly better than the 115° computation for Waukegan, since it predicts a larger-amplitude surge there and smaller time interval between reflected surge and first following depression. However, both computations fail to predict the early arrival of the reflected surge. This failure probably is related to the bow shape of the squall line causing the surge. The surge set up by the curved squall line conceivably did not lag much behind the line at the western extremity, so that the first surge arrived soon after the squall-line passage. Apparently the curvature of the squall line did not affect so much the internal timing of the disturbance. The amplitudes predicted by the computations (both 115° and 95°) are smaller than the observed amplitudes.

## ACKNOWLEDGMENTS

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